GLOBAL CHANGE IMPACT ON SOIL FAUNA AND ECOSYSTEMS

JOSEF RUSEK*

Institute of Soil Biology, Academy of Sciences of the Czech Republic, České Budějovice

1. INTRODUCTION

Global climate controls the distribution of biomes on the earth. Soil types are an inseparable part of each ecosystem and thus exhibit the same general geographical distribution as biomes. The macroclimate of mountains is modified by decreasing temperatures associated with height, giving rise to ecosystem units arranged into altitudinal belts. The forest, subalpine, alpine and nival belts or zones are comparable to biomes such as boreal forest, tundra, and arctic desert.

Ecologists are trying to find indicators of global climate change. Ecotones, the transitional zones between adjacent ecological systems, are universal features on the face of the earth, occurring in tropical, temperate and polar regions. Hence, the study of ecotones provides a useful method for monitoring global change. The most vulnerable areas on the earth should have priorities in monitoring climatic changes, e.g. high latitude and altitude zones, lowland and wetland regions, etc. (*Dyer et al., 1989*).

Grabherr et al. (1994) compared data on cover and abundance of vascular plant species with historical records on 26 summits exceeding 3 000 m in the Alps. Species richness increased during the past few decades and changes were more pronounced at lower altitudes. The mean annual temperature in Austria has increased during the last 90 years by 0·7°C, and this warming can theoretically lead to a shift in the altitudinal vegetation belts at a rate of 8 – 10 m per decade. During long-term studies, *Rusek (1993)* also reported significant changes in some alpine ecotones and ecosystems in Tatra National Park (Slovakia). Some of these changes were caused by long-distance transported acid deposits, but others were connected to global warming.

Geomorphological configuration also influences markedly the mesoclimatic and microclimatic conditions on mountains. Therefore many different ecosystems are often distributed over small areas that reflect wind conditions, snow cover duration, soil solifluction processes, sun radiation or water conditions. During my long-term studies of soil animal communities and some other ecosystem components in Tatra National Park (since 1959) and in Central Bohemia (since 1967) certain biotic ecosystem-component changes were observed that are signalling global climate change.

This contribution presents data on soil collembolan communities in long-term studied mountain ecosystems, as well as in lowland relic ones, which demonstrates connections between faunal responses and global climate change. One example is chosen to show how ecosystem changes influence hydrology of a whole mountain system and adjacent regions.

2. SITE DESCRIPTION

One study area is situated in the west part of the Tatra National Park (Slovakia) and includes the Tomanova Dolina Valley with surrounding mountain ridges. The lowest point corresponds to 1 225 m, the highest one 2 122 m above sea level (ASL). The geology of the area is characterized by granite and pegmatites south of the Tomanovy Potok Stream and by limestone with smaller outcrops of werfenic shales forming the northern part.

* Address: Na sádkách 7, 370 05 České Budějovice, Czech Republic

Ranker soils, brown soils, podzols, and boggy soils are formed on the acidic bedrocks, and different types of mountainous rendzinas on the limestone.

The climate of the whole area is of the cold alpine type, with an average annual temperature of 0°C and average July temperature of 10°C, and with yearly precipitation of 1 750 mm. Frequent occurrence of strong winds blowing over the mountain ridges is typical. Forty-five plant communities were recognized in the area under study (*Unar et all., 1984, 1985*). In 25 of these plant communities, permanent plots were established in 1959 for long-term studies of soil mesofauna and other biotic and abiotic parameters (*Rusek, 1993*). Four of the plant communities were selected to show the characteristic changes caused by global warming and the influence of ecosystem alteration on the hydrological regime:

1. Festucetum versicoloris calcicolum *Szafer et al. 1923* – Southern slope of Hvizdalka (1750 m ASL), below a transversal rocky ridge, on limestone.
2. Festucetum carpaticae *Domin, 1925* – Southern slope of Hvizdalka (1 700 m ASL), on limestone.
3. Geranio-Alchemilletum crinitae *Hadac et al., 1969* – On the southern slope of Hvizdalka (1 750 m ASL) in the northern shallow gully, on limestone.
4. Sphagno-Empetretum hermaphroditi *Unar, 1984* – On the northern slope of Polska Tomanova (1 780 m ASL), 60 cm thick mat of Sphagnum-moss on granite.

The second study area is situated in central Bohemia (Czech Republic) in the Voderadske Buciny Nature Reserve near Jevany, about 35 km east of Prague. The geology of the area is characterized by Ricany granite and permian sand- and siltstones. The whole territory was geomorphologically formed during the Pleistocene and it bears many periglacial features. Brown soils, podzols, pseudogleys and rankers are the most frequent soil types. The average annual temperature is 7·5°C and average July temperature is 17·8°C, with yearly precipitation of 620 – 660 mm. Twenty-four types and subtypes of beech, oak and spruce forest communities are recognized in this area (*Cvancara and Samek, 1957*).

In 20 of these forest types, permanent plots were established in 1967 – 1970 for long-term studies of soil mesofauna and other biotic and abiotic ecosystem parameters. Five of the forest types were selected for this present contribution to show characteristic changes documenting global warming:

5. Luzuleto-Fagetum cladonietosum (type with Dicranum scoparium) – Top of the Nad Farmou Hill, about 435 m ASL. Soil type: shallow ranker soil, without litter layer.
6. Luzuleto-Fagetum cladonietosum (type with Dicranum scoparium) – Lesni Potok Catchment, U Kazatelny, 445 m ASL. Soil type: shallow ranker soil, without litter layer.
7. Luzuleto-Fagetum typicum – E-slope below location No. 5, Nad Farmou Hill, 425 m ASL. Soil type: brown soil with 5 – 10 cm deep L-layer.
8. Luzuleto-Quercetum cladonietosum – E-slope of the Kounata Hill, 450 m ASL. Soil type: shallow ranker soil, without litter layer.
9. Carpineto-Fagetum – Plateau below Hranicni Olsina in the Lesni Potok Catchment, 480 m ASL. Soil type: brown soil with 2 – 3 cm deep litter layer.

Table 1. Density of Collembola (individuals/100cm^2) in selected ecosystems of the Tomanova Dolina Valley (location numbers see Site description).

Species	Locations: / Year of sampling:	1		2		3		4	
		1968	1990	1968	1990	1968	1990	1968	1990
Folsomia manolachei Bagnall, 1939		6	165	48	53	42	244	6	458
Protaphorura armata (Tullberg, 1869)		6	6	10	22	23	31	-	-
Isotomiella minor (Schäffer, 1896)		1	11	1	20	2	-	-	152
Isotoma violacea Tullberg, 1876		-	-	-	2	42	37	1	-
Friesea truncata Cassagnau, 1958		-	15	-	7	5	14	16	111
Tetracanthella fjellbergi Deharveng, 1987		-	170	-	-	-	-	4	1726
Oreogastrura parva (Gisin, 1949)		-	1	1	19	-	-	-	-
Parisotoma notabilis (Schäffer, 1896)		-	-	2	15	2	1	-	-
Lepidocyrtus lignorum (Fabricius, 1781)		-	2	3	-	3	-	-	-
Pseudanurophorus binoculatus (Ksen., 1934)		-	38	2	4	-	6	-	-
Folsomia penicula Bagnall, 1939		-	-	-	27	-	26	-	-
Folsomia sensibilis Kseneman, 1936		61	-	21	-	-	6	-	-
Megalothorax minimus Willem, 1900		-	-	1	1	-	-	-	2
Orchesella frontimaculata Gisin, 1946		-	-	-	-	-	8	-	-
Folsomia alpina Kseneman, 1936		17	-	-	-	-	-	-	-
Entomobrya juv.		11	-	-	-	-	-	-	-
Ceratophysella sigillata (Uzel, 1891)		2	-	1	-	-	-	1	-
Mesaphorura tenuisensillata Rusek, 1974		2	2	-	2	5	3	1	-
Isotoma sp. juv.		1	2	-	-	-	-	-	1
Willemia aspinata Stach, 1949		1	-	-	-	-	-	-	-
Tomocerus minor (Lubbock, 1862)		1	-	1	-	-	-	1	-
Mesaphorura sylvatica (Rusek, 1971)		-	4	2	-	-	-	-	-
Micranurida sp.		-	1	-	-	-	-	-	2
Sphaeridia pumilis (Krausbauer, 1898)		-	-	1	-	-	-	-	-
Pseudosinella zygophora (Schille, 1908)		-	-	9	-	-	-	-	-
Pseudachorutes subcrassus Tullberg, 1871		-	-	2	-	-	-	-	-
Pseudosinella alba (Packard, 1873)		-	-	2	-	-	-	-	-
Willemia anophthalma Börner, 1901		-	-	2	1	4	-	-	1
Mesaphorura italica (Rusek, 1971)		-	-	-	29	-	3	-	-
Jevania fageticola Rusek, 1987		-	-	-	1	-	-	-	-
Karlstejnia rusekiana Weiner, 1983		-	-	-	1	-	-	-	-
Ceratophysella engadinensis (Gisin, 1949)		-	-	-	9	32	37	-	-
Friesea albida Stach, 1949		-	-	-	5	-	-	-	-
Friesea mirabilis (Tullberg, 1871)		-	-	-	1	-	-	-	-
Odontella sp.		-	-	-	1	-	-	-	-
Mesaphorura macrochaeta Rusek, 1976		-	-	-	-	-	1	-	-
Tullbergia simplex Gisin, 1958		-	-	-	-	-	2	-	-
Ceratophysella succinea (Gisin, 1949)		-	-	-	-	6	-	-	-
Stenaphorura quadrispina Börner, 1901		-	-	-	-	1	-	-	-
Anurida sp.		-	-	-	-	1	-	-	-
Pseudisotoma monochaeta (Kos, 1942)		-	-	-	-	-	1	-	28
Sminthurinus aureus v. signata Krausb., 1898		-	-	-	-	-	1	-	2
Mesaphorura hylophila Rusek, 1982		-	-	-	-	-	1	-	-
Proisotoma recta Stach, 1930		-	-	-	-	-	-	17	-
Isotoma neglecta Schäffer, 1900		-	-	-	-	-	-	5	-
Neanura alba Törne, 1956		-	-	-	-	-	-	1	5
Protaphorura illaborata (Gisin, 1952)		-	-	-	-	-	-	-	21
Protaphorura cancellata (Gisin, 1956)		-	-	-	-	-	-	-	14
Onychiurus granulosus Stach, 1930		-	-	-	-	-	-	-	1
Lepidocyrtus peisonis Traser and Christ.,1992		-	-	-	-	-	-	-	1
Xenylla boerneri Axelson, 1905		-	-	-	-	-	-	-	10
Pseudachorutes parvulus Börner, 1901		-	-	-	-	-	-	-	1
Entomobrya lanuginosa (Nicolet, 1841)		-	-	-	-	-	-	-	1

Table 2. Density of Collembola (individuals/100 cm^2) in selected ecosystems at Voderadske Buciny Reserve (location numbers see Site description).

Species	Locations: / Year of sampling:	5 1971	5 1995	6 1995	7 1971	8 1994	9 1995
Tetracanthella fjellbergi Deharveng, 1987		235	165	-	1	15	20
Isotomurus balteatus (Reuter, 1876)		11	-	2	-	-	2
Mesaphorura sp. n.		12	-	16	1	2	30
Folsomia manolachei Bagnal, 1939		4	2	2	-	51	38
Bourletiella pistillum Gisin, 1946		4	-	-	-	-	-
Isotomiella minor (Schäffer, 1896)		5	1	15	37	32	102
Mesaphorura hylophila Rusek, 1982		2	1	-	2	1	2
Micranurida candida Cassagnau, 1952		2	-	-	-	-	8
Doutnacia xerophila Rusek, 1974		1	-	-	-	-	-
Pseudachorutes parvulus Börner, 1901		1	-	-	-	1	-
Pseudisotoma sensibilis (Tullberg, 1871)		1	-	8	-	-	-
Anurophorus atlanticus Fjellberg, 1974		1	-	42	-	-	-
Pseudosinella bohemica Rusek, 1979		1	5	1	-	8	1
Hypogastrura socialis (Uzel, 1891)		-	345	-	-	3	-
Ceratophysella denticulata (Bagnall, 1941)		-	7	7	4	-	-
Mesaphorura yosii (Rusek, 1967)		-	8	3	-	9	6
Proisotoma minima (Absolon, 1901)		-	4	-	-	-	-
Proptaphorura armata (Tullberg, 1869)		-	4	30	15	22	22
Folsomia penicula Bagnall, 1939		-	2	-	-	-	-
Pseudosinella zygophora (Schille, 1908)		-	1	-	-	-	-
Folsomia quadrioculata (Tullberg, 1871)		-	1	-	143	-	-
Isotoma notabilis Schäffer, 1896		-	1	-	9	-	1
Protaphorura vanderdrifti (Gisin, 1952)		-	1	-	-	3	-
Entomobrya corticalis (Nicolet, 1842)		-	1	-	-	-	-
Anurophorus septentrionalis Palissa, 1966		-	-	43	-	-	-
Xenylla boerneri Axelson, 1905		-	-	114	-	38	9
Friesea claviseta Axelson, 1900		-	-	2	-	-	-
Mesaphorura macrochaeta Rusek, 1976		-	-	2	-	52	31
Mesaphorura tenuisensillata Rusek, 1974		-	-	1	-	5	6
Paratullbergia callipygos (Börner, 1903)		-	-	1	-	1	-
Protaphorura subuliginata (Gisin, 1956)		-	-	-	-	-	1
Friesea truncata Cassagnau, 1958		-	-	3	7	-	-
Oncopodura sp.		-	-	1	-	-	-
Lepidocyrtus juv.		-	-	1	-	-	-
Lepidocyrtus lanuginosus (Gmelin, 1788)		-	-	-	3	9	-
Lepidocyrtus lignorum (Fabricius, 1781)		-	-	-	-	1	-
Micranurida sp. n. 1		-	-	-	-	56	8
Willemia aspinata Stach, 1949		-	-	-	3	5	-
Willemia anophthalma Börner, 1901		-	-	-	4	15	3
Protaphorura humata (Gisin, 1952)		-	-	-	-	2	-
Onychiurus granulosus Stach, 1930		-	-	-	36	5	-
Onychiurus denisi Stach, 1934		-	-	-	4	1	-
Entomobrya nivalis (Linné, 1758)		-	-	-	1	8	-
Micranurida pygmaea Börner, 1901		-	-	-	-	-	1
Micranurida sp. n. 2		-	-	-	-	-	6
Pseudosinella alba (Packard, 1873)		-	-	-	1	-	1
Lipothrix lubbocki (Tullberg, 1872)		-	-	-	2	-	-
Sphaeridia pumilis (Krausbauer, 1898)		-	-	-	1	-	-

3. METHODS

The same methods were used for all nine locations during the long-term studies of soil mesofauna communities. Ten soil samples of 10 cm^2 surface area and 5 cm deep were collected at each location and sampling date using a cylindrical metal soil corer. Soil samples were extracted using Tullgren-funnels (*Rusek, 1993*).

4. RESULTS AND DISCUSSION

Changes in the alpine collembolan communities were observed in Tatra National Park for the period between 1977 to 1990, as earlier stated for some of these ecosystems (*Rusek, 1993*). The alpine collembolan species *Folsomia alpina*, bound in the past to the endemic plant community *Festucetum versicoloris*, died out in the study area. *Tetracanthella fjellbergi*, restricted in the past to acid bedrock soils only, invaded some soils on limestone because of their acidification. The same was probably true for the arcto-alpine species *Pseudanurophorus binoculatus*. Conversely, some species occurring in the past predominantly and in high densities only in lowland and lower mountain forests were now dominant also in the alpine zone above the subalpine *Pinus mugo* belt, e.g. *Folsomia penicula* and *Mesaphorura italica*. This upward shift in collembolan species could be attributed to global warming. This explanation also holds for the upward retreat of the arcto-alpine *Folsomia sensibilis* from the same localities on limestone (Tab. 1). *Folsomia sensibilis* will very likely be found in high densities in other ecosystems of higher elevation on limestone as it was in the case of ecosystems on granite. The occurrence of many other forest or typically lowland species in the ecosystems of the

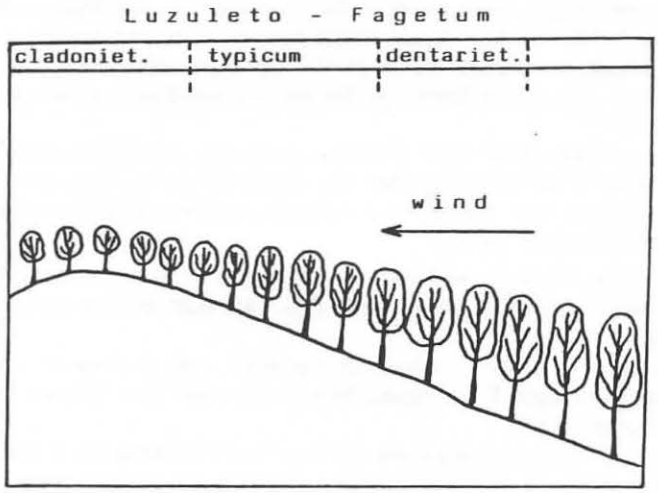

Fig. 1. Distribution of different subtypes of beech forests in the Voderadske Buciny Reserve. The relic arcto-alpine collembolan community, in *Luzuleto-Fagetum cladonietosum*, occurs on hill summits. It is conditioned by a hill-top wind phenomenon.

alpine zone was not yet characterized by high densities, but the number of such species was relatively high (*Jevania fageticola, Karlstejnia rusekiana, Mesaphorura macrochaeta, Sminthurinus aureus v. signata, Onychiurus granulosus, Pseudachorutes parvulus, Xenylla boerneri, Entomobrya lanuginosa* and others) (Tab. 1). The process of upward movement of the alpine, subalpine and montane soil fauna is comparable with that of the alpine-nival flora in the Alps as observed by *Grabherr et al. (1994)*, and its rate in the case of some soil collembolan species (e.g. *Xenylla boerneri* and *Folsomia penicula*) is higher than with the plants.

Another type of alpine ecosystem change was determined in 1992 on the northern slopes of the Tomanova Dolina Valley on granite bedrock at location No. 4 not visited since 1976. The former *Sphagno-Empetretum* ecosystem was completely changed by the nitrogen supply in acid deposits. The formerly 60 cm thick carpet of live *Sphagnum-moss* died out and disappeared completely. A new ecosystem of *Oreochloetum distichae* with quite another plant and soil animal community, as well as soil type, was established there by 1992 (Tab. 1, location 4). The former collembolan community that was typical for wet boggy alpine habitats, with low species diversity, was replaced by a new community with high density, high species diversity, and numerous euedaphic species. The *Sphagno-Empetretum* ecosystem had a very high water holding capacity and its dying out in areas extending some km^2 in the investigated and adjacent valleys led to a significant water decrease in the Tichy Potok Stream during the summer period (about 1·2 m lower water level). The *Sphagno-Empetretum* ecosystem was widespread in the Western, High and Low Tatras (*Horak 1971, Unar et al. 1985*). The disappearance of an ecosystem in an area of hundreds of km^2 could significantly influence the hydrology of thousands of km^2 of the landscape.

The second study-area at Voderadske Buciny Natural Reserve represents a large forest complex where some ecosystems are inhabited by relic soil animal communities from the Pleistocene glacial periods, when the whole area was in the periglacial climatic zone. Many geomorphological features and soil animal communities are still reflecting this ancient climate impact. Climate inversion in deep and narrow valleys along the Jevansky Potok Stream enables spruce (*Picea excelsa*) to grow there. A hill-top wind phenomenon, which blows away litter from the soil surface during fall and winter, retards the succession of beach forest communities on and near hill summits. The resulting soils do not develop beyond an initial ranker stage (Fig. 1). This enables *Luzuleto-Fagetum cladonietosum* and *Luzuleto-Quercetum cladonietosum* forest stands to be preserved at such sites. These ecosystems contain a relic soil animal community of Pleistocene origin (at least since the last continental glaciation) that is characterized by the arcto-alpine or alpine collembolans *Tetracanthella fjellbergi, Bourletiella pistillum* and *Isotomurus balteatus*, as well as other species not presented in the selected samples (Tab. 2).

In the past, *Tetracanthella fjellbergi* reached extremely high densities (more than 20 000 specimens on $1\ m^2$) in the solifluction ranker soils in the *Luzuleto-Fagetum cladomietosum*, and it was also numerous in the *Luzuleto-Quercetum cladonietosum*. It was accompanied by the less numerous relic *Bourletiella pistillum* and *Isotomurus balteatus*. Currently, in some stands with the mentioned relic ecosystems, *T. fjellbergi* is still dominant (16 500 specimens on m^2), but in others this collembolan species is missing or is present in very low densities (Tab. 2). It has been replaced by *Hypogastrura socialis*

and xerothermic species such as *Anurophorus atlanticus, Anurophorus septentrionalis* and *Xenylla boerneri. Bourletiella pistillum* was not found in the recent samples, and *Isotomurus balteatus* became very rare. On the other hand, many species characteristic of the adjacent climax forest communities (compare locations 7 and 9 in Tab. 2) have invaded the relic ones. This signalizes climatic changes that are not favourable to relic arcto-alpine and alpine species. It is difficult to tell which climatic factor is responsible for these major ecosystem changes. The invading xerothermic species may indicate global warming, but the retreating or missing relic species could indicate global warming together with changes in the precipitation patterns during the year. It is difficult to imagine that the populations of relic species died out in the long period since glaciation and again established themselves in the high populations recorded in the 1970s. The relic soil animals could not here to higher altitudinal zones as was established in the Tatra National Park, and as the vascular plants have done in the Alps (*Grabherr et al., 1994*). Therefore changes of relic arcto-alpine soil animal communities in lowland could be used also as indicators of global climate change.

5. CONCLUSIONS

1. Alpine soil mesofauna (Collembola) reacts sensitively to global climate change. Some arcto-alpine species are dying out in alpine ecosystem at lower altitude and their niches are being occupied by forest and other lowland and mountain forest species. Many lowland or mountain collembolan species of lower density are increasing their diversity (species number) in some alpine ecosystems.

2. Arcto-alpine and alpine soil collembolan species and their communities in relic lowland ecosystems (e.g. *Luzuleto-Fagetum cladonietosum)* react to global warming by decreasing their density and dying out. Xerothermic and later on mesophilous euedaphic species are invading certain ecosystems that are loosing their relic features.

3. Some major ecosystem changes caused by different factors (e.g. nitrogen supply from acid deposits in the case of the alpine ecosystem dominated by *Sphagnum*-moss) may change hydrologic conditions, sometimes over large areas.

4. Soil fauna react sensitively to climate change and could be used for monitoring such change.

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